

# **A Utility Maximization Model for Evaluation of Health Care Programs**

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*A linear health utility scale is described, complete with measurement instruments, that allows assignment of utility values to health states for any disease or treatment program. Given that the change produced by a health care program in the health states of a population is determinable, this utility scale permits assessment of the effectiveness of that program in terms of the change it produces in overall health utility. This is the basis of a model that will rank programs by their effectiveness/cost ratios or select them into a subset achieving the maximum effectiveness under specific cost or other constraints. Two algorithms are described, suitable respectively for priority ranking and for selection of programs giving maximum effectiveness under constraints, and the application of the model is discussed.*

The evaluation of a health care program implies that the program has a determinable impact on the health of the target population; when the effect of the program is to improve health, the problem is to decide whether the improvement justifies the cost of the program. If a number of programs are involved, each with known effect and known resource requirements, and the resources are insufficient to implement all programs, the question is how to determine the optimal subset that should be implemented. On a larger scale, if the components of the total health service system are partitioned into mutually exclusive programs, one can ask how limited resources may be optimally allocated within the entire system. The difficulty of assigning appropriate values to all the effects of a given program, on the one hand, and, on the other hand, of making interprogram comparisons of values that may be disease-dependent or program-dependent has in the past placed limitations on these more ambitious goals of evaluation.

Two principal analytic approaches suggested for the evaluation of public programs have been cost-benefit analysis and cost-effectiveness analysis. Cost-benefit analysis [1] attempts to identify all relevant costs and benefits of each program and to evaluate each in terms of dollars in the year in which it will occur. Programs are compared on the basis of their net present value of benefits

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less costs. In applying this technique to health programs [2-5], researchers are faced with the difficult problem of assigning a dollar value to the benefit of improved health. The recommended approach of using increased earnings fails to define many types of benefits such as the dollar value of improved health for housewives, retired people, and others with no earnings; the dollar value of increased patient comfort with no change in prognosis; and the dollar value of a reduction in mental pain and suffering for the patient and his family. Recent work by Klarman [2,3] and by Mishin [6] offers proposals to overcome some of these deficiencies, but significant measurement problems are involved in attempting to implement these proposals.

Cost-effectiveness analysis [7-9] avoids the cost-benefit problems mentioned above by measuring the health impact of a program in nonmonetary units only, that is, in terms of its "effectiveness." The health improvement in nonmonetary units is then compared with the cost in dollars to determine the effectiveness/cost ratio for the program. Unfortunately, the nonmonetary measure of health improvement used is frequently disease- or program-specific, e.g., cases found, cases treated, prevalence reduced, lives saved, life-years gained, or disability days reduced. Such measures preclude interprogram comparisons and thus seriously limit the usefulness of the approach.

Recent work has been directed at the development of a scale for measuring health improvement that is disease- and program-independent [10-13]. With such a scale, cross-program comparisons can be made while retaining the advantages of the cost-effectiveness approach.

An adequate scale might range from 0 for death (with negative values assigned to fates "worse than death," if they exist) to 1 for good health (defined as the absence of physical, mental, and social disabilities and symptoms). With such an index, every individual could be assigned a number from 0 to 1 representing his level of health. If a specific health care program improves the health of some persons, they will move to a higher level of health sooner than they would have otherwise, and the amount of this health improvement can be readily calculated in terms of index days (health days). Here the index days of health improvement would represent the amount of health improvement on the scale multiplied by the number of days this improvement was in effect. Furthermore, the index day would be disease- and program-independent and could be used to determine the amount of health improvement for any type of health care program. In this way different health care programs could be compared with respect to the amount of health improvement produced as well as their cost, to determine their relative cost-effectiveness. This is the essence of the utility maximization model described in this article.

## Health Utility Index

Basic to the model is the concept of a morbidity-mortality health index that determines a utility value for every possible health state. None of the approaches to such an index proposed by other researchers [10-13] is considered

satisfactory for the needs of this model, and a new approach founded on utility theory has been developed.

Health has been defined by the World Health Organization as “a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity.” By this definition, health is a three-dimensional phenomenon consisting of physical, emotional, and social components. Each dimension has a large range of possible states, varying from perfect health to total absence of function. The health state of an individual can be defined as a point in three-dimensional space, with the axes representing physical function ( $x_1$ ), emotional function ( $x_2$ ), and social function ( $x_3$ ). Most points in this three-dimensional space are feasible—people may at times be functioning quite poorly on one of the three scales and yet quite well on the other two.

The index value assigned to a particular health state is the *utility of that state as perceived by society*, and the model allocates resources in the health service system so as to maximize the total health utility to society. If  $h$  represents the index value,  $h$  is a function of the health state:  $h = f(x_1, x_2, x_3)$ . Rather than attempting to define this function explicitly, however, the index value  $h_i$  for any health state of interest ( $i = 1, 2, \dots, n$ ) is measured directly, by defining the health state precisely and then employing a utility-measurement technique on an appropriate sample of subjects from the population of interest. The utility of a particular health state will differ for each individual in the sample and, indeed, will vary over time for any one individual. The general index, however, is an aggregate utility for a population of interest and thus exhibits greater stability. The arithmetic mean is the appropriate aggregation technique consistent with the proposed decision criterion—maximization of the expected utility gain over the population of interest.

The measurement technique used produces a linear interval scale. For convenience the healthy state ( $i = 1$ ) is arbitrarily assigned a value of one ( $h_i = 1$ ) and the dead state ( $i = n$ ) a value of zero ( $h_n = 0$ ).

### Health Index Measurement

In measuring the utility of a health state, one must consider the effect of the length of time spent in that state. It appears that the utility of a highly confining health state (e.g., one that entails bed confinement) is a decreasing function of time, whereas the utility of an inconvenient but less confining state is an increasing function of time [14], as shown schematically in Fig. 1. This paradoxical situation is easier to understand if one asks himself the following questions: “Which would I prefer (i.e., which has the higher utility for me), one day of bed confinement or one day on a kidney-dialysis regimen, with identical prognoses?” and “Which would I prefer, five years of bed confinement or five years on a kidney-dialysis regimen, with identical prognoses?” Most respondents would prefer bed confinement for the short duration but the dialysis regimen for the longer one.

The measurement techniques developed in this study measure the average utilities  $h_i$  and  $h_j$  directly, thus avoiding the difficult task of determining the

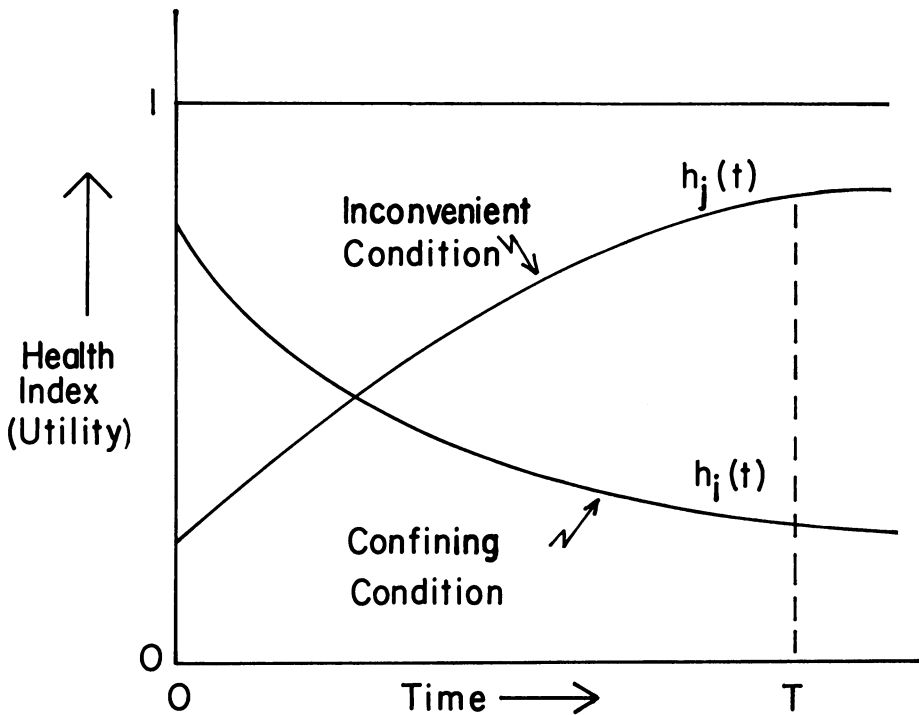


Fig. 1. Effect of time on health state utilities.

actual functions  $h_i(t)$  and  $h_j(t)$ . Since the result is an average utility for a specific length of time, however, it cannot be used to represent the utility of that state for different lengths of time. Thus it becomes important to carefully determine the duration for a particular health state before measuring its utility and to control this duration properly during the measurement process.

A second matter of concern is the effect of prognosis on the utility of a health state. The health index for a particular state is intended to represent the utility of that state, unaffected by the utility of future states that may or may not follow. Favorable or unfavorable prognoses are incorporated into the model at a later stage of the analysis. In the determination of utilities, the effect of prognosis is eliminated by holding the prognosis constant for each alternative in the measurement procedure.

A final concern is the effect of financial considerations on the utility of a health state. The model attempts to allocate society's scarce resources so as to maximize the health utility achieved as perceived by society, and it assumes that society will arrange the necessary transfer payments to effect the optimal allocation so determined. The cost factors are incorporated at a later stage of the analysis and must not be allowed to interfere with the measurement of the pure utilities. In practice, this is achieved by asking the respondent to imagine that he is fully insured—complete medical insurance, salary-continuation insurance,

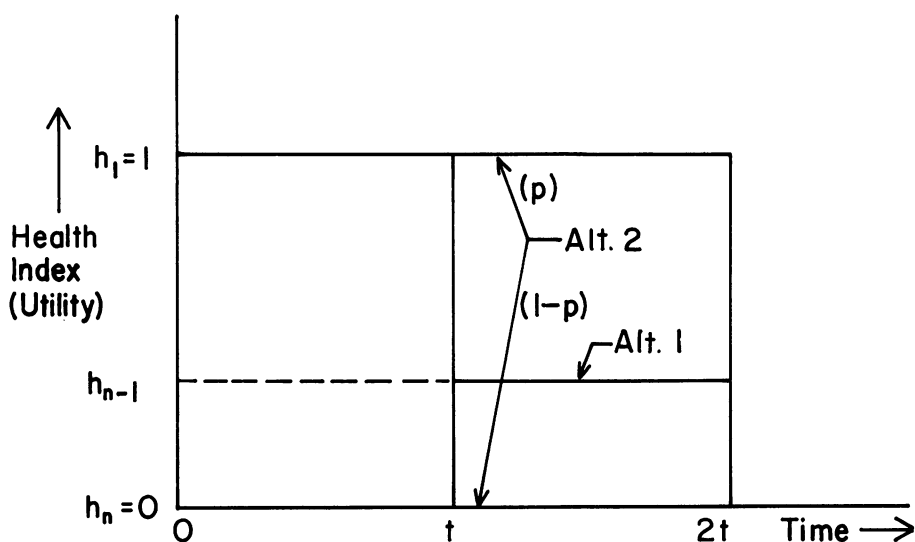


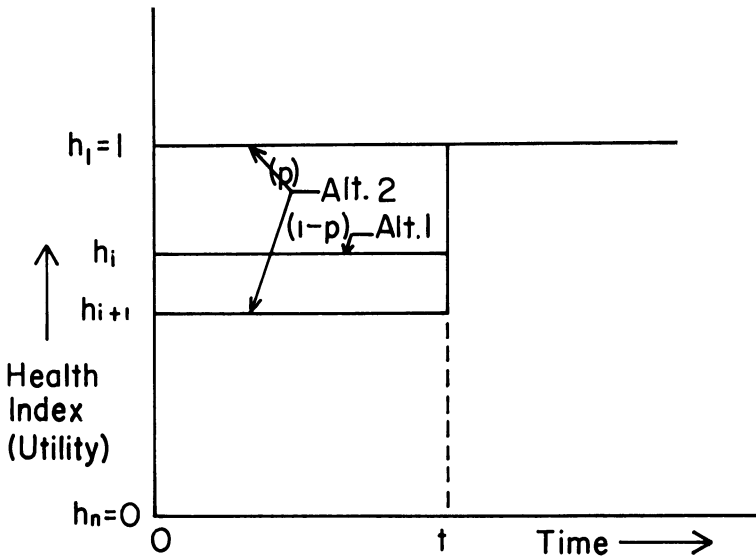
Fig. 2. Standard gamble for state  $n - 1$ .

and life insurance—so that regardless of the outcome, there are no financial implications for him or his family.

A technique is required that can be applied to a sample of individuals to measure the utility to them of specific health states on a linear scale. An analysis of available techniques led to the selection of the von Neumann-Morgenstern standard gamble [15] as one appropriate method and to the development of a new technique, the “time trade-off method,” as an alternative.

In measuring the utility of a particular health state, the first step is the determination of the time period of interest,  $t$ . If several states with identical time periods are to be measured, they can conveniently be grouped together. The procedure for measuring such a group begins by asking the subject to preference-rank the states assuming a time period  $t$  for each state and assuming identical prognoses. Let  $i = 2, 3, \dots, n - 1$  represent the preference rankings for a particular respondent ( $i = 1$  and  $i = n$  being reserved for the reference states, healthy and dead, respectively). The utilities for this respondent are then measured by the use of either the von Neumann-Morgenstern standard gamble approach or the time trade-off technique.

*The von Neumann-Morgenstern Standard Gamble.* Figure 2 shows the application of the classic von Neumann-Morgenstern standard gamble technique to state  $n - 1$ , the morbidity state least preferred in the ranking. The subject is asked to choose between two alternatives: alternative 1, the certainty of good health for time  $t$ , then state  $n - 1$  for time  $t$ , followed by death; and alternative 2, the gamble of good health for time  $t$ , followed by use of a hypothetical drug with a probability  $p$  of keeping the subject completely asymptomatic for time  $t$ , followed by death, and a probability  $1 - p$  of causing immediate death. The

Fig. 3. Standard gamble for state  $i$ .

probability  $p$  is varied to locate the point at which the respondent is indifferent between these two alternatives. At this indifference point the utilities of the two alternatives are equal and the utility of state  $n - 1$  may be calculated as follows:

$$h_1 t + h_{n-1} t = h_1 t + h_i t p + h_n t (1 - p)$$

Since by definition  $h_1 = 1$  and  $h_n = 0$ , this simplifies to

$$h_{n-1} = p$$

The apparently superfluous requirement that in each alternative the respondent begins by being healthy for time  $t$  is in fact necessary to ensure that at all times the respondent is dealing with his future death and never with his immediate death. This precaution not only improves the reliability of the resultant utilities but is also consistent with their eventual use: the utilities are to be used in planning decisions concerning future health programs, consequently the trade-offs to be evaluated will all be in the future.

Figure 3 shows the application of the standard gamble technique for any state  $i$  other than state  $n - 1$ . Here alternative 1, the certainty alternative, is state  $i$  for time  $t$  followed by good health, whereas alternative 2, the gamble alternative, is use of a hypothetical drug with a probability  $p$  of immediate cure and a probability  $1 - p$  of making the subject worse by putting him in state  $i + 1$  for time  $t$ , followed by good health. Again the probability  $p$  is varied to locate the indifference point, and again the required utility is calculated by equating the utilities of the two alternatives. This yields

$$h_i = p + h_{i+1} (1 - p)$$

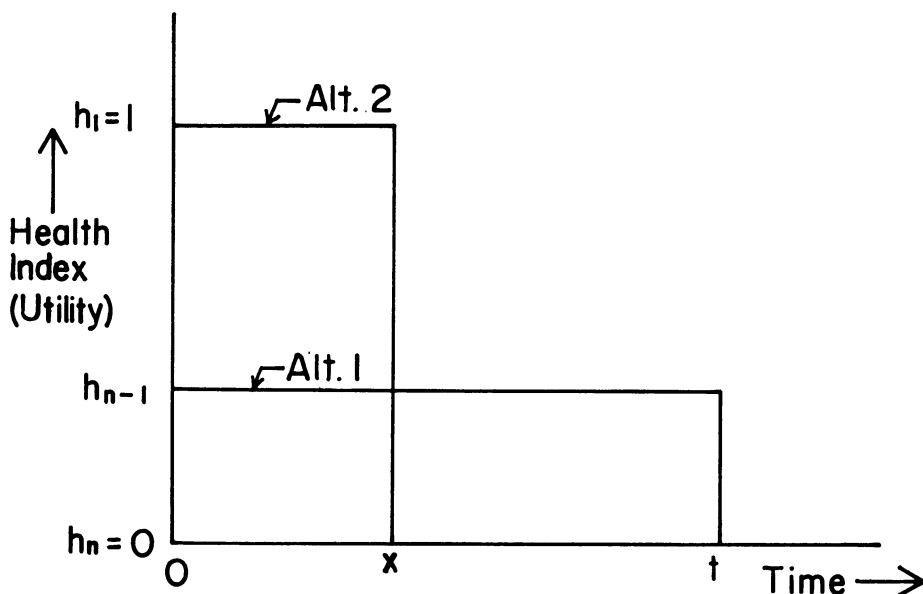


Fig. 4. Time trade-off for state  $n - 1$ .

It should be noted that the utility for each state  $i$  could be measured in the same way as that for state  $n - 1$ , but the above approach has two advantages: it avoids continual reference to the state of death and, more important, it avoids extreme indifference probabilities (close to 1.0), which are difficult to estimate.

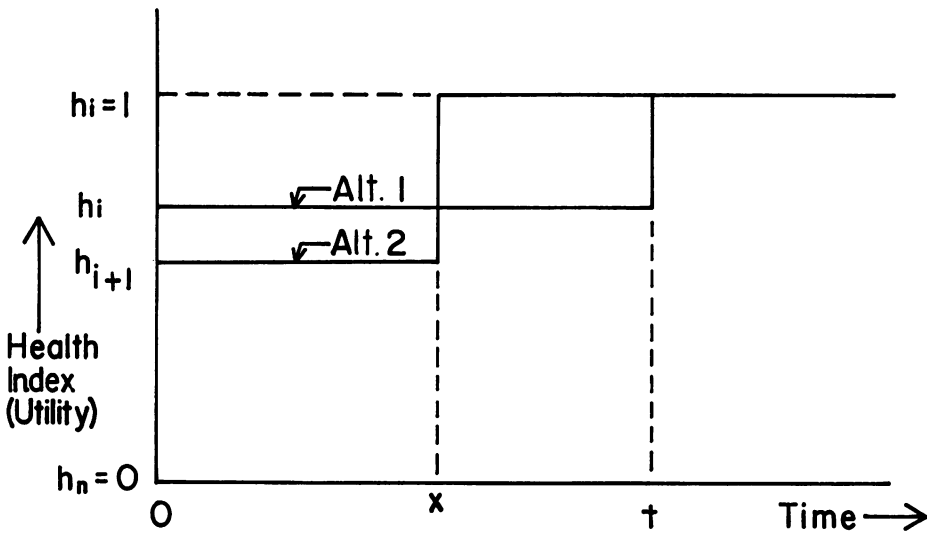
*The Time Trade-off Method.* Figure 4 shows the application of the time trade-off method to state  $n - 1$ . Here the respondent is asked to choose between two alternatives of certainty: alternative 1, state  $n - 1$  for time  $t$ , followed by death; and alternative 2, good health for time  $x < t$ , followed by death. The respondent's indifference point is located by varying the time  $x$ . The average utility for state  $n - 1$  over time period  $t$ ,  $h_{n-1}$ , is again determined by equating the utilities of the two alternatives:

$$\begin{aligned} h_{n-1}t &= h_1x + h_n(t - x) \\ h_{n-1} &= x/t \end{aligned}$$

Figure 5 shows the application of this method to any state  $i$  other than state  $n - 1$ . The two certainty alternatives are alternative 1, state  $i$  for time  $t$ , followed by good health; and alternative 2, state  $i + 1$  for time  $x < t$ , followed by good health. The required utility is calculated from

$$h_i = 1 - \frac{x}{t} (1 - h_{i+1})$$

In a pilot application of these utility measurement techniques [14], the time trade-off technique and the von Neumann-Morgenstern standard gamble method

Fig. 5. Time trade-off for state  $i$ .

produced equivalent and reliable results, but the time trade-off technique was found easier to administer.

## Utility Maximization Model

### Effectiveness and Cost Measures

The health utility index values provide the data required to calculate the effectiveness of a health care program in terms of health days. In a given situation, the number of health days can be determined by summing the health indexes for each person each day over the population and the time period of interest. Fortunately, the problem can be simplified by appreciating that in all cases, two or more programs are being compared; the interest is in differences between programs rather than absolute measures. Therefore the basic data needed are the number of man-days changed from one health state to another as a result of the program being evaluated. These changes are measured from a base-line situation, usually the continuation of the status quo. The basic effectiveness computation then proceeds as follows: From an analysis of the program under consideration, determine  $d_{jk}(y)$ , the number of man-days changed from health state  $j$  to health state  $k$  during the year  $y$ . To avoid counting each change twice—a possibility because  $d_{jk}(y) = -d_{kj}(y)$ —let

$$D_{jk}(y) = \max [0, d_{jk}(y)]$$

Next, define  $E(y)$  as the health effectiveness of the program in year  $y$ , measured

in health days and representing the change in health utility caused by the program during year  $y$ . It can be found from

$$E(y) = \sum_{j=1}^n \sum_{k=1}^n D_{jk}(y) (h_k - h_j)$$

where  $h_j$  and  $h_k$  are the utilities of states  $j$  and  $k$ , respectively. From  $E(y)$  one can calculate  $E$ , the change in health utility (health effectiveness) for all years affected by the program:

$$E = \sum_{y=1}^{\infty} \frac{1}{(1+r)^y} E(y)$$

where  $r$  is an annual discount rate relating future changes to their equivalent present value. Substitution for  $E(y)$  yields the following formula for the health effectiveness of the program:

$$E = \sum_{y=1}^{\infty} \frac{1}{(1+r)^y} \sum_{j=1}^n \sum_{k=1}^n D_{jk}(y) (h_k - h_j) \quad (1)$$

In practice, the summation over  $y$  can be truncated at a value sufficiently large so that, because of the discounting factor, little error is introduced.

The cost of the program, like the effectiveness, is also measured in terms of changes from the base-line situation. The cost has four components:

$C_1(y)$  is the direct cost of the program in year  $y$ .

$C_2(y)$  is the indirect cost of the program in year  $y$  (earnings lost owing to program participation).

$C_3(y)$  is the reduction in the direct costs of health care in year  $y$  as a result of the program.

$C_4(y)$  is the reduction in the indirect costs of disease, disability, and death in year  $y$  as a result of the program. (The indirect costs are measured in terms of lost earnings.)

$C_1$  and  $C_2$  represent resources consumed by the program.  $C_3$  and  $C_4$  represent resources released or created by the program. Thus the total cost of the program to society in year  $y$  is:

$$C(y) = C_1(y) + C_2(y) - C_3(y) - C_4(y)$$

and the total cost of the program over all years, with future costs discounted at an annual interest rate  $i$ , is:

$$C = \sum_{y=1}^{\infty} \frac{1}{(1+i)^y} C(y) \quad (2)$$

As in Eq. 1, the discounting factor permits a reasonable abbreviation of the number of years included in the summation.

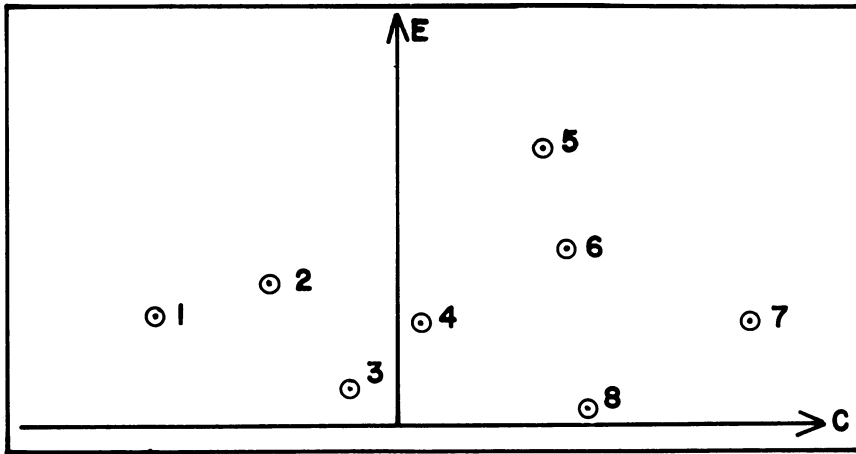


Fig. 6. Independent programs on a C-E graph.

### Optimization

Once the cost and the health effectiveness of each program have been calculated, the problem becomes one of determining which programs should be implemented and what level of funding should be provided to each. The overall criterion is to select those programs which will produce the maximum health effectiveness within a given set of constraints. To implement this criterion, one needs to know the health effectiveness  $E$  of each program, from Eq. 1; the total cost to society  $C$  of each program, from Eq. 2; and the constraints on the solution.

Most health programs can be funded at a number of different levels, and most conform to the law of diminishing marginal returns; that is, doubling the expenditure does not double the benefits. Therefore, there are two questions for each program: Should this program be implemented? And if so, at what level of funding? A convenient method for handling this situation is to treat each feasible funding level of each program as though it were a completely separate program, gather the data accordingly, and then, in the optimization algorithm, define the different levels of the same program as mutually exclusive programs.

Two approaches to the optimization problem were investigated: a cost-effectiveness-ranking algorithm developed expressly for this study and a standard mathematical programming model.

*Cost-effectiveness-ranking Algorithm.* If the only resource constraint on the solution is one of total cost, a cost-effectiveness-ranking algorithm may be used to determine the health program priorities. This technique can be readily illustrated through the use of a cost-effectiveness graph, shown in Fig. 6. Consider a number of independent programs, each with total cost and total effectiveness  $c$  and  $e$ , respectively. (Negative values of  $e$  are possible but can be quickly dismissed by stipulating that a program that reduces the health of the population will not warrant further consideration.) The programs shown in Fig. 6 are numbered in their cost-effectiveness priority order. Let  $c_i$  and  $e_i$  be the cost and the

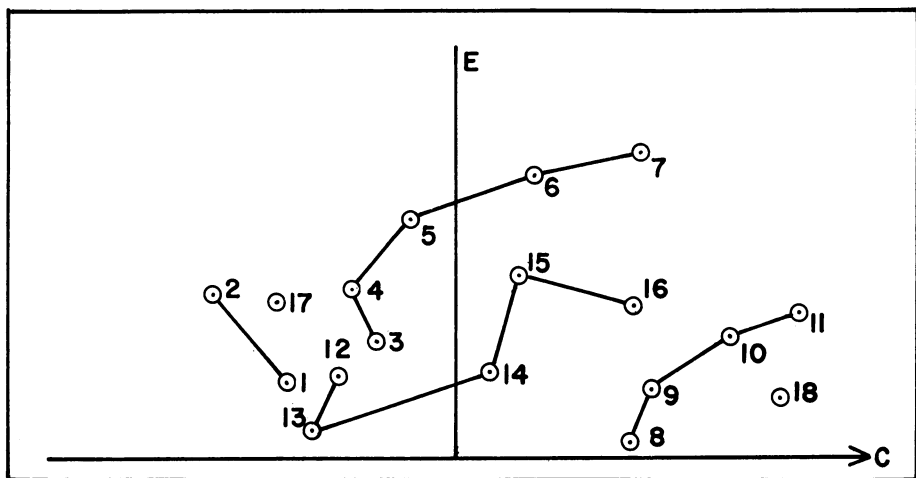


Fig. 7. Mutually exclusive programs on a C-E graph.

effectiveness, respectively, of program  $i$ . The criteria for ranking independent programs are:

Criterion 1: If any costs  $c_i$  are nonpositive, these programs have top priority and are ranked in ascending order of  $c_i$ . In case of a tie, select the program with the maximum  $e_i$  first.

Criterion 2: The remaining programs are ranked in descending order of  $e_i/c_i$ , their effectiveness/cost ratio. In case of a tie, select the program with minimum  $c_i$  first.

Criterion 1 can be explained as follows: Health programs with a negative cost to society create more resources than they consume. These programs should have a higher priority than programs with a positive cost, since their implementation frees resources for use in other programs. Among those programs with negative costs, the best is the one with the most negative cost, regardless of their respective health benefits. The justification for this view can be appreciated when one investigates the implications of any other choice. Consider, for example, the situation if program 2 of Fig. 6 were implemented rather than program 1, because of its greater health benefit. This decision would cost society  $c_2 - c_1$  dollars of opportunity cost to obtain a health improvement of  $e_2 - e_1$ , and this might not be particularly good value in terms of the health improvement gained per dollar spent. However, if the projects are implemented according to criterion 1, there are no opportunity costs to society for the health benefits gained.

Criterion 2 is self-evident, merely reflecting the fact that total funds are limited and therefore programs with positive costs should be implemented in descending sequence of their health effectiveness yield per dollar.

The case with mutually exclusive programs is more involved but follows the same general arguments as above. Figure 7 shows a C-E graph in which the connected points depict a set of mutually exclusive programs. Such points

might also represent different funding levels for the same program. The algorithm for this case is based on marginal costs and effectiveness. Suppose that program 5 is under consideration and the question is whether or not to replace it with program 6. The cost of such a replacement will be  $c_6 - c_5$  dollars, to gain  $e_6 - e_5$  units of health. This must be compared against all other possibilities for adding programs to the solution at this step, so that the best possible program addition is made.

The cost-effectiveness-ranking algorithm developed for use with mutually exclusive programs follows:

1. For each set of mutually exclusive programs, determine the best initial program and add it to the list of candidate programs.
  - a. If a set has any  $c_i < 0$ , the best initial program is the point with the minimum  $c_i$ . In case of a tie, select the point with the maximum  $e_i$ .
  - b. If a set has no  $c_i < 0$ , the best initial program is the point with the maximum  $\Delta E/\Delta C$ . (For the initial list,  $\Delta E/\Delta C = e_i/c_i$ .) In case of a tie, select the point with the minimum  $\Delta C$ —this will cause the tied programs to be adjacent on the final priority listing in ascending sequence of program cost.
2. Select the best program from the list of candidate programs, using the same criteria as in step 1 above, and enter it into the solution.
3. Replace this program in the list of candidate programs by the next best program from the same mutually exclusive set. If program  $r$  is currently in the solution, the replacement for it is that program  $i$  which maximizes  $\Delta E/\Delta C$ ,  $\Delta E > 0$ , where  $\Delta E = e_i - e_r$  and  $\Delta C = c_i - c_r$ . In case of a tie, select the increment with the minimum  $\Delta C$ .
4. Repeat steps 2 and 3 until programs for consideration are exhausted.
5. The sequence with which programs enter the solution gives their cost-effectiveness priority ranking.

This algorithm has been programmed and implemented on a time-shared computer system. (The program listing is available in the original research [14].) The basic output of the algorithm is a list of programs ranked in their cost-effectiveness priority sequence; cumulative and marginal costs and effectiveness can be obtained. One may use the output to advantage by selecting programs in sequence from the list until a desired health improvement has been achieved, which will yield the minimum-cost set for that health improvement; or until the cumulative cost has reached a cost constraint, which will yield the set that maximizes the health improvement for that cumulative cost.

In either case, the set of programs so selected may not represent the final decision. There are other factors not normally included in quantitative analysis that should be weighed by the decision maker in his final deliberations; these intangible factors may include political considerations, public attitudes, organizational considerations, and satisfactions for the patients and the health professionals involved in the program.

*Mathematical Programming.* An alternative approach to this optimization problem is to use a standard zero-one integer programming formulation. Here

the basic model, equivalent to the problem solved by the cost-effectiveness-ranking algorithm, is formulated as follows:

$$\begin{aligned}
 &\text{Maximize} && \sum_{i=1}^n e_i x_i \\
 &\text{subject to} && \sum_{i=1}^n c_i x_i \leq C \\
 & && x_i = 0, 1 \quad i = 1, 2, \dots, n \\
 & && \sum_{i \in I_j} x_i \leq 1 \quad j = 1, 2, \dots, p
 \end{aligned}$$

where  $x_i = 1$  indicates that program  $i$  is accepted

$x_i = 0$  indicates that program  $i$  is rejected

$e_i$  is the effectiveness of program  $i$

$c_i$  is the cost of program  $i$

$C$  is the total budget available

$I_j$  is a set  $j$  of mutually exclusive programs

The major advantage of this formulation is its great flexibility in handling additional constraints. For example, suppose it is desired to constrain the amount of physician time, the amount of nurse time, and the number of hospital bed-days separately to no more than the total amounts respectively available,  $P$ ,  $F$ , and  $B$ . Let  $p_i$ ,  $f_i$ , and  $b_i$  be the amounts of each of these resources used by program  $i$ . Then the following three additional constraints would be included:

$$\sum_{i=1}^n p_i x_i \leq P$$

$$\sum_{i=1}^n f_i x_i \leq F$$

$$\sum_{i=1}^n b_i x_i \leq B$$

Note that this formulation allows the analyst, through parametric analysis, to investigate the marginal value of additional units of each type of resource. That is, it can answer the question: How much additional health would be created by adding an additional unit of physician time, of nursing time, or of hospital beds?

Those familiar with mathematical programming will appreciate that further constraints can readily be added to handle any number of more complicated variations of this basic problem. Unless additional constraints are required, however, it has been found [14] that the basic problem as formulated here is best solved by the vastly more efficient cost-effectiveness-ranking algorithm.

### Application: A Hypothetical Example

To illustrate the use of the model, consider three hypothetical programs that are to be evaluated. Program A has three feasible funding levels, A1, A2, and A3, to be considered as distinct programs; program B has two, B1 and B2; and C has only one funding level. Assume that two health states  $x$  and  $y$  are involved, and that these states have durations of approximately one year; further, assume that the average health index for each of these states with this duration is either known or can be determined by using one of the measurement techniques described earlier on an appropriate sample of people. The health index values used in the example are  $h_x = 0.75$  and  $h_y = 0.60$ . (Recall that the values for good health and for death are 1 and 0, respectively.)

Valid data are also needed concerning the effect of the programs on health in the population. For example, program A1 might have the result that 10 persons who would otherwise have died will spend one year in state  $y$  and then be healthy, with an average remaining life expectancy of 20 years; and 100 persons who would otherwise have spent one year in state  $y$  will instead spend one year in state  $x$ . Using Eq. 1 and assuming an annual discount rate of 0.08 applied over a period of 21 years (to take proper account of the 20-year period following one year of program operation), the equivalent present value for the effectiveness of one year of program A1 is approximately 40 000 health days. This and the values hypothesized for the other programs are shown in Table 1.

Table 1. Total Effectiveness and Total Cost of Hypothetical Programs

Program	$E$ , thousands of health days	$C$ , thousands of dollars
A1	40	-30
A2	120	10
A3	130	50
B1	60	20
B2	70	40
C	40	40

The cost of each program is also shown in Table 1. Program A1, for example, is assumed to have a direct cost,  $C_1(1)$ , of \$200 000 in the year of operation; its indirect cost in the year of operation,  $C_2(1)$ , is \$13 000. The reduction in future direct costs,  $C_3(y)$ , is zero for all  $y$ ; the reduction in future indirect costs after the first year is \$25 000 per year for 20 years:  $C_4(y) = \$25\,000$  for  $y = 2, \dots, 21$ . The total program cost calculated from Eq. 2 is approximately -\$30 000, a negative cost quite possible in reality.

Given the effect and cost data shown in Table 1, the ranking algorithm de-

Table 2. Cost-effectiveness Ranking of Hypothetical Programs

Program	Rank	Marginal effectiveness $\Delta E$ , thousands of health days	Marginal cost $\Delta C$ , thousands of dollars	$\Delta E/\Delta C$	Cumulative	
					$E$ , thousands of health days	$C$ , thousands of dollars
A1	1	40	-30	n.a.	40	-30
B1	2	60	20	3.0	100	-10
A2	3	80	40	2.0	180	30
C	4	40	40	1.0	220	70
B2	5	10	20	0.5	230	90
A3	6	10	40	0.25	240	130

scribed earlier will yield the priority listing shown with the marginal and cumulative costs and effectiveness values in Table 2. These results, appropriately interpreted and qualified, would be considered along with an analysis of any associated intangible factors in making a final decision.

## Discussion

The utility maximization model that has been described takes a society-wide view of costs, in that the program cost determined by Eq. 2 is the total of all resources consumed less those created. The model is flexible enough, however, so that other cost definitions could be readily substituted if desired. Benefits (i.e., health days) are assumed to be additive. This is a consequence of the linearity of the health index scale, which assigns to a health improvement from 0.8 to 1.0 twice the value of an improvement from 0.9 to 1.0, and of the fact that every person's health is given the same weight. The contribution of one health day to the indicated program effectiveness is the same whether the person experiencing that day of health is a newborn, a 25-year-old male, or an 85-year-old grandmother. If desired, the model could easily be modified to handle other weighting assumptions.

Further research into health indexes would be useful to develop a general health utility scale that would eliminate the present need to measure specific utilities for each application of the model; nevertheless, the health index described here should prove independently useful for measuring, comparing, and monitoring community and national health levels. The model seems to have no inherent limitations as to the types of health care programs to which it is applicable. The requirement for accurate data about the effect of a given program on patient outcomes can presumably be met by appropriate health care experimentation; otherwise, currently available data may constitute a practical limitation. While the scope of applicability requires verification by further research, it appears that, given adequate data, the model could be used to optimize the total health service system, allocating health resources to programs and activities so as to maximize the overall health utility achieved.

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